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## AN OVERVIEW OF EUROPEAN SPACE TRANSPORTATION SYSTEMS

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## AN OVERVIEW OF EUROPEAN SPACE TRANSPORTATION SYSTEMS

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### Summary

/1\*

With the completion of the launch rocket series ARIANE 1 to 4, Europe will have reached the same capacity to transport commercial payloads as the USA has with the Space Shuttle and the kick stages which are presently operative. The near-term development of these capacities would require Europe to develop a larger launch rocket, "ARIANE 5." Further motivations for this rocket are access to manned spaceflight, the development of Europe's own space station, and the demand for shuttle technology. Shuttle technology is the subject of research being done in France on the winged re-entry vehicle "Hermes." Operation of the European space station "Columbus" will require development of an interorbital transport system to facilitate traffic between the space station's various segments.

All European space transportation systems will have to match their quality to that of the other countries involved in space flight. All areas of development are marked not only by possible cooperation but also by increased competition because of increasing commercialization of space flight.

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\*Numbers in the margin indicate pagination in the foreign text.

## 1. Launch Rocket\* Series ARIANE 1 - 4

ARIANE launch rocket models 1 - 3 are being operated at present in Europe. The three-stage rocket, with storable fuels in the first two stages and the cryogenic combination of  $H_2/O_2$  in the third, is designed for transport into geostationary transfer orbit (GTO) (see fig. 1).

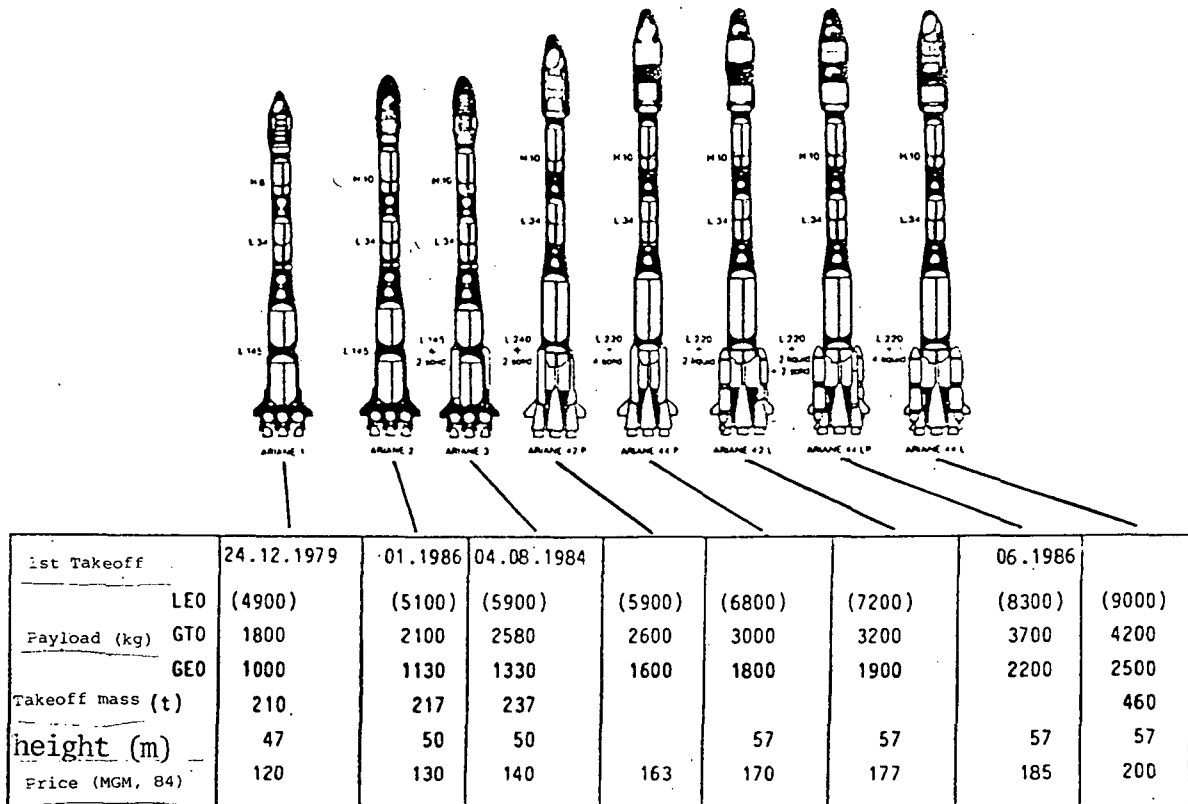


Figure 1: Launch rocket series ARIANE 1 - 4 (Numbers in parentheses are calculated values; the structural load limits the payload to 4300 kg.)

ARIANE 1 has taken off 11 times to date (as of August 1985). These include the two renowned failures, when combustion instabilities occurred in the first-stage engines during the second takeoff (May, 23, 1980), and the third-stage turbopumps failed during the fifth takeoff (September 10, 1982). Since

\*Editor's Note: in this translation "-4-" "launch rocket" should be "carrier rocket".

that time, however, ARIANE has enjoyed a spotless success record, including three takeoffs to date by the ADRIANE 3. The ARIANE 2 was developed from the first model by increasing /3 the power of the Viking engines (stages 1 and 2) and the HM7 engine (stage 3), as well as by enlarging stage 3 from 8 to 10 t of fuel. The Viking engine's fuel combination of  $N_2O_4$ /UDMH was changed to  $N_2O_4$ (UDMH + 25% hydrazine hydrate = "UH 25") to eliminate combustion chamber pressure fluctuations while increasing combustion chamber pressure (from 53.5 to 58.5 bar). This model's first flight is not anticipated until 1986, based on demand. ARIANE 3, on the other hand, had its first takeoff in 1984. It is structurally similar to the ARIANE 2, except for two additional solid boosters (each of which has 71 t thrust and 7.35 t fuel) [1].

ARIANE 1 took off on July 2, 1985 for the second-to-last time (with the comet probe GIOTTO). It is not to be used again after its final takeoff in November of this year (with the French Earth observation satellite SPOT). ARIANE 2 is to takeoff for the first time in 1986 (twice with INTELSAT-V satellites, once with the German TV-Sat). Otherwise, the more powerful ARIANE 4 model will be available beginning in 1986 (for the first time in July with TDF-1 or Meteo-sat). This model was developed from the ARIANE 3 by increasing fuel in stage 1 from 145 to 220 t, as well as by selective inclusion of 2 to 4 strap-on boosters, each having 9.5 t solid fuel (each with 71 t thrust) or 40 t liquid fuels (67 t thrust each through a Viking 6 engine). Variations of booster type and number provide a series of 5 transports with staged payload capacity. The development of the ARIANE series was a consequence of the market situation in the sector of commercial satellite transportation.

## 2. Trans-Atlantic Competition

Approximately 70% of all civilian takeoffs so far have involved geostationary telecommunication satellites, a situation which, according to all mission analyses, is not likely to change in the future. The development of material processing in space (space processing, material sciences) is certainly an unknown factor, but in the realm of earth observation it is a certainty that it will never account for much more than 1% of telecommunications.

The payload capacities into geostationary orbit (GEO) and geostationary transfer orbit (GTO) shown in Figure 2 testify to the fact that the ARIANE series 1 - 3 has competed successfully (also with regard to costs) with the US Delta and Atlas-Centaur carriers. The satellite masses which the US Space Shuttle (STS) can transport to GEO aided by the perigee-stages <sup>/5</sup> of the PAM-series from McDonnell Douglas [2] also lie in the same range, while another apogee engine is required for ARIANE. However, as early as 1983 and with the advent of Boeing's IUS (inertial upper stage) system [3], the STS attained a payload class of which ARIANE is not capable. The satellite masses which can be transported by different versions of the Titan (among others, also with IUS) lie in the same range, as well. Of late, however, these transports\* have been used exclusively for military missions. Beginning in 1986, this range will be accessible to Europe as the result of the ARIANE-4 series. To date, Arianespace has profited from operating the ARIANE because PAM and IUS are relatively expensive systems, and because competition existed within the US itself between the non-retrievable US transports and the STS. According to NASA, this competition will have been eliminated by mid-1987.

\*Editor's Note: in this translation "transports" should be "carrier vehicles"

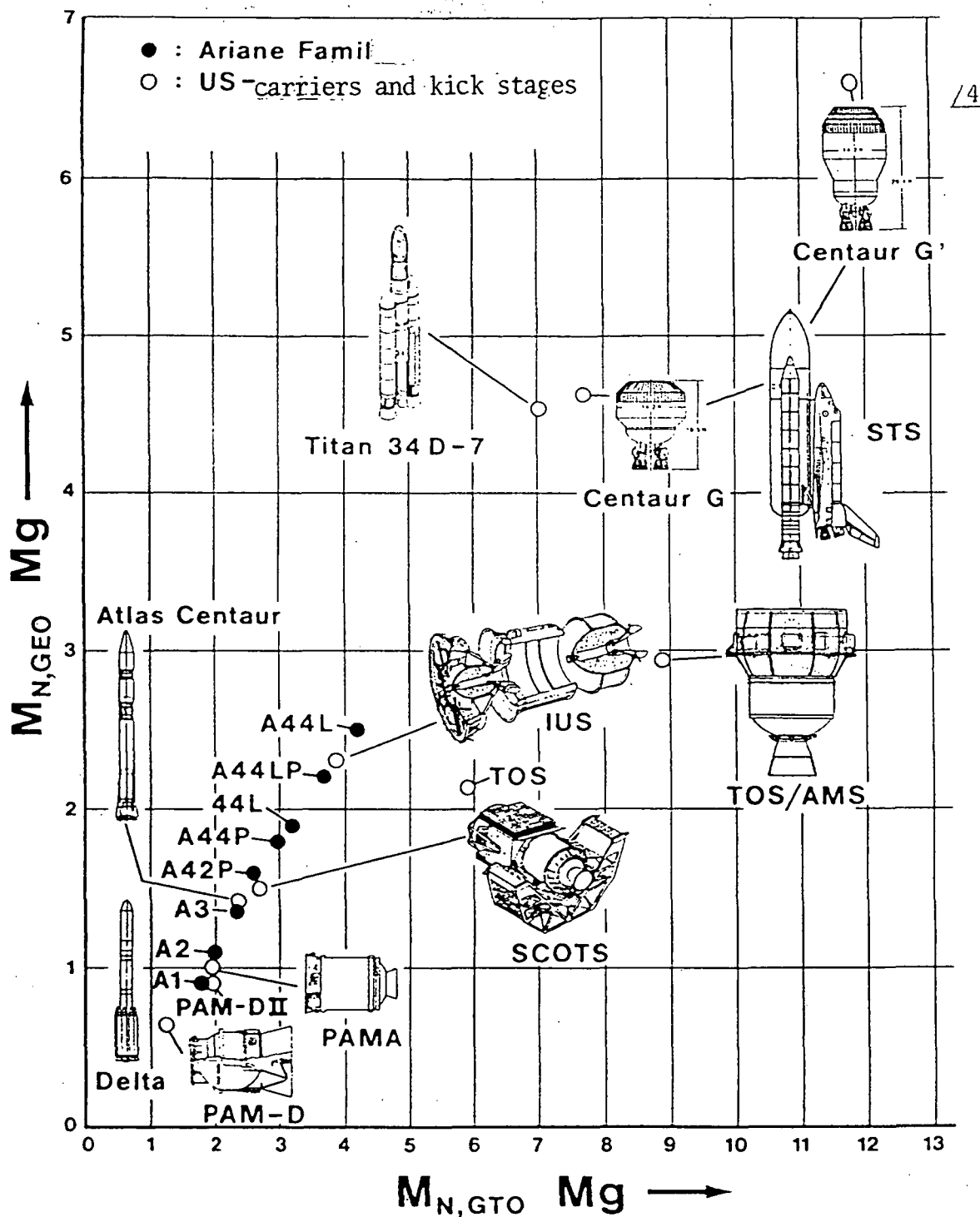


Figure 2: Payload Capacity to GEO and GTO for ARIANE Series Compared to US Transports. (Note: Equivalent GTO capacities are given for transfer stages with LEO-GEO transport capacities.) Black dots = ARIANE series, White dots = US Transports and Kick Stages

McDonnell Douglas has stopped producing the Delta, of which only 5 more examples exist. A private firm (Transpace Carriers Inc.) is endeavoring to keep this carrier on the market. General Dynamics Convair is interested likewise in continued commercial use of the Atlas, although only 5 more takeoffs are anticipated up to 1987. There is already agreement that the Titan should not continue to be used for military payloads.

In addition to PAM and IUS, many other kick stages which can be employed with STS will come on the market:

- The perigee stage SCOTS (shuttle compatible orbital transfer system), developed by RCA, will be used beginning in 1986 for their "RCA-4000" telecommunication satellites. The interface for the payload on the SCOTS is designed so that it can be used on ARIANE 4, as well, without any changes [5].
- Another solid fuel perigee TOS (transfer orbit stage) stage is being developed by Martin Marietta in agreement with Orbital Sciences Corporation as an economical replacement for IUS and is to be ready for takeoff already by 1986 [6]. Beginning in 1988, the payload range of the IUS is to be exceeded by the TOS in connection with the second stage AMS (apogee and maneuvering stage), which will be equipped with an RS-51 11.6 kN liquid fuel engine designed by Rocketdyne.

-- The availability of the large CENTAUR-G<sup>1</sup> (General Dynamics Convair) is guaranteed beginning in 1986. It is to be used for the first time at the takeoff of the Jupiter probe Galileo. Based on its engine capacity, this model affords the STS a new dimension in GEO-payloads (6600 kg), but, because of the volume limit of 30 kg/m<sup>3</sup>, only considerably smaller



satellites (approximately 4000 kg) will fit in the cargo space next to the 8.87 m long stage

-- For this reason, CENTAUR G, a shorter (5.94 m) version, is being developed. It will be able to transport over 4600 kg to GEO and leaves a length of approximately 12 m available in the cargo space [7]. The same payload can be attained by the Titan 34D-7 (being developed at present by Martin Marietta) in combination with the IUS, so that at least the USAF will not have to depend on the STS/CENTAUR G combination.

Since these developments have been known for some time it has become evident in Europe that to remain competitive, it would be necessary to expand payload capacity while simultaneously reducing specific transport costs. Since the ARIANE series exhausted possibilities of contemporary design with the advent of ARIANE 4, the question of future European launch rockets has been under investigation (above all by the French CNES, as well as by the ESA) since 1981. The question of corresponding engine technology goes hand-in-hand with this research.

### 3. The HM60 Engine and European Engine Technology

The first ideas to expand upon ARIANE 4 involved a new second stage for the ARIANE 4. The new second stage was to be equipped with a new motor (M) with a high-energized (H) hydrogen/oxygen base and 60 t thrust. The resultant concept, designated "HM60", had already established itself by 1980, although most engine parameters and ideas regarding ARIANE 5 changed continuously over the following years. The probable final HM60 engine version, "A5P," is characterized by very conventional technical details, the result of a nearly 15-year-long pause in the European development of engine technology.

This fact can be seen by comparing (see Figure 3) all the conventional  $H_2/O_2$  engines ever developed or tested in the West and Japan. (Compare also, Table 1 which contains the essential technical data on these engines.)

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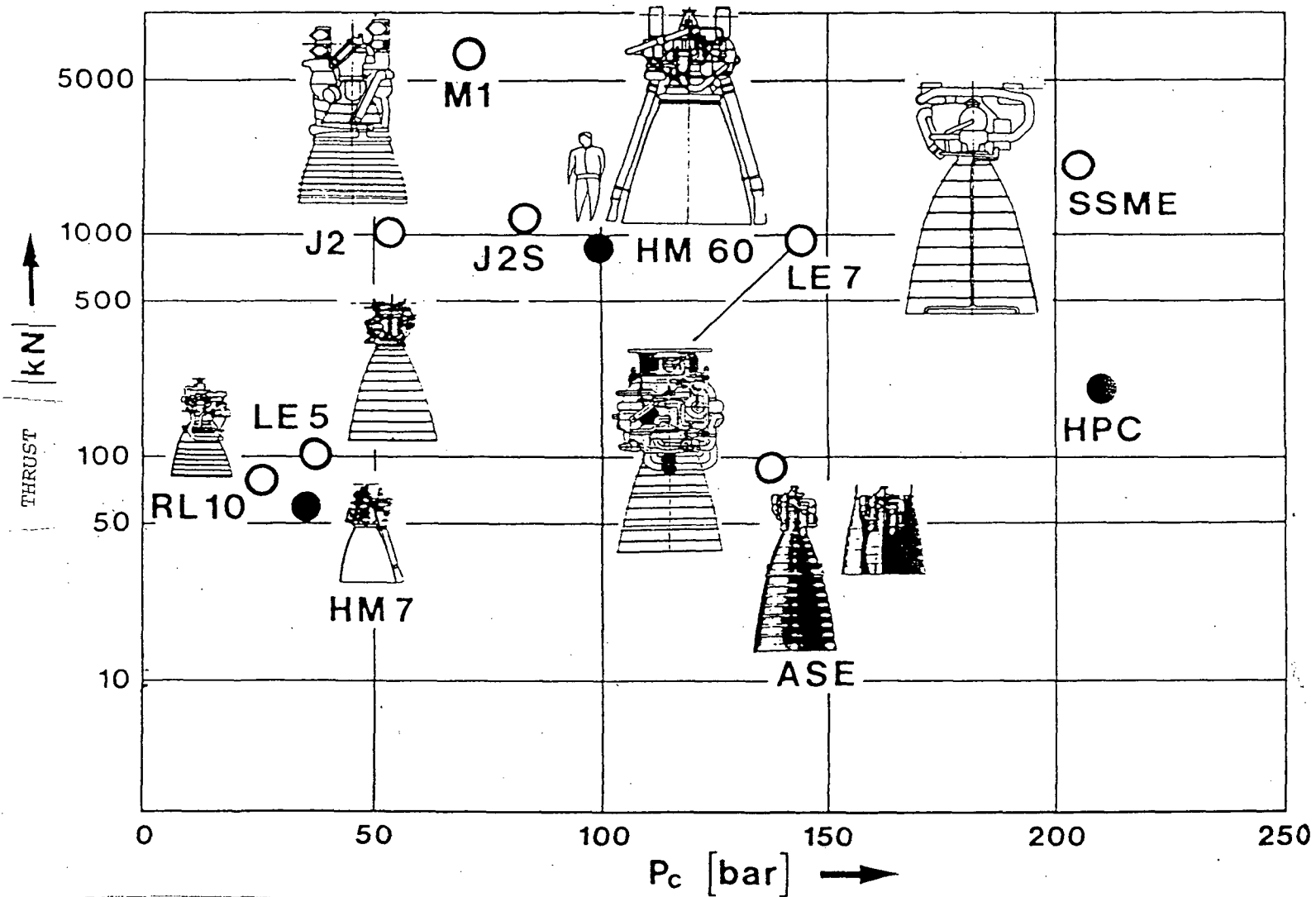


Figure 3: Thrust and Combustion Chamber Pressure of  $H_2/O_2$  Engines (See text for discussion; shaded symbols represent European engines.)

Induction Current* Engines:	J2	J2S	M1	HM7-A	HM7-B	LE-5	HM60
Thrust [kN]	1068	1171	6671	61,7 (Vac)	62,6 Vac)	103 (Vac)	880
Combustion Chamber Pressure [bar]	55,2	79,3	70	30,1	35,5	36,8	100
O/F Mixture Ratio [-]	4,5 - 5,5	5,5		4,4	4,8	5,5	5,3 - 6,5
Specific Impulse [sec]	425	441	430	442,6	444,6	445	445
reference	[10]	[10],[11]	[11],[12]	[13],[14]	[14]	[15]	[11]
Main Current** Engines:	RL-10		SSME		ASE		LE-7
Thrust [kN]	80 (Vac) 8 (idle)		1816 (SL) 2277 (Vac) 1181-2482		89 (Vac)		932 (Vac)
Combustion Chamber Pressure [bar]	27,6		220,6		138		150
M/F Mixture Ratio [-]	5,0		6,0		6,0		6,0
Specific Impulse [sec]	441		455		476		447
reference	[10],[16]		[17]		[10],[18]		[19]

Table 1: Cryogenic Engines from USA, Japan, and Europe

\*Editor's Note: "induction current engine" should be "auxiliary flow engine". "Main current engine" should be "primary flow engine".

(SL = sea level and/or ground thrust, Vac = thrust in vacuum. Thrust values without indicators are based on ground conditions.)

- RL-10, developed by Pratt & Whitney between 1958 /9 and 1963 for the Centaur upper stage, is the first and, at the same time, very successful cryogenic engine having main current expander cycle with 1 turbine on the LH<sub>2</sub> pump, and engines to the LOX pump. It can be re-fired in flight. It has been in use from 1963 to present. In addition to this engine, Pratt & Whitney offered an alternative STS main engine in 1971 [7].
- J2 was developed by Rocketdyne between 1960 and 1962 for the second stage of the Saturn I in the Apollo Program. It has an induction current engine with turbine exhaust-film cooling in the nozzle. It is equipped with 1 gas generator with 2 turbines working in series; it can be re-fired\* in flight. It has not been used since the end of the Gemini Program in 1966.
- J2-S was developed by Rocketdyne between 1961 and 1966 for the second stage of the Saturn IB and Saturn V. It is structurally similar to J2. It has not been used since the end of the Skylab Program in 1973.
- M1 was developed by Aerojet Liquid Rocket Co. beginning in 1962 as an experimental large engine for technological purposes. In 1971, Aerojet offered an alternative STS main engine based on experience gained from this experiment [9].
- SSME, Space Shuttle Main Engine, was developed by Rocketdyne between 1970 and 1981 for the STS. It has a high-pressure main current-staged combustion cycle with 2 pre-combustion chambers, 2 turbines, and 2 high-pressure turbopumps; main current expander cycle for the LH<sub>2</sub> low-pressure pumps, and high-pressure LOX drive for the LOX low-pressure pumps. It meets qualifications for manned flight. It cannot be

-12-

\*Editor's Note: in this translation "re-fired" should be "re-started".

re-fired in flight. However, one developmental goal is reusability (40 times) with 6.0 hours minimum operational life. By March 1985, this goal had been fulfilled by only 23%, due to the limited lifespan of the turbine blades of the LH<sub>2</sub> high-pressure pump at 109% thrust (upper design limit).

- ASE, Advanced Space Engine, was developed by NASA in 1972 at Rocketdyne under agreements on construction of the high-pressure main current-staged combustion engine. Its cycle is similar to the SSME, however, because of its smaller dimensions, the storage load on the LH<sub>2</sub> turbopumps is even greater than for the SSME. Development of this engine was interrupted in 1979 because of difficulties with the SSME.
- HM7 was developed by SEP between 1973 and 1979 under contract from CNES and ESA as the third stage H8 of the ARIANE rockets. It has induction current engine with 1 gas generator and 1 turbine on the LH<sub>2</sub> pump with drive to the LOX pump. It cannot be re-fired in /10 flight. Failure of the engine led to a crash of the third stage during takeoff L05. It was flown successfully 6 times thereafter with ARIANE 1, and 3 times in an improved version HM7-B with ARIANE 3.
- LE-5 has been under development by NASA/NAL since 1977 as the engine for the second stage of the Japanese H-1 transport. Completion date goal is 1986. It has an induction current engine with 1 gas generator and 2 turbines, turbopumps in series, and nozzle film cooling using turbine exhaust. It can be re-fired a number of times in flight.
- LE-7 has been under development by NASA/NAL since 1982 as the engine of the core stage of the Japanese H-11

transport, aimed for use in approximately 1993. It has high-pressure main current engine with stage combustion cycle.

- HM60 has been in developmental stages since 1980. Beginning December 1984, it has been developed as the official ESA project at SEP under contract from CNES as the engine for the core stage for the European launch rocket ARIANE 5P, planned for use in 1995. It has medium-pressure induction current engine with 1 gas generator and 2 turbines, and turbopumps operating parallel without engines. It cannot be re-fired. Qualifications for manned flight remain open.

Figure 4 depicts the combustion cycle of this engine. It can be started only once with the solid gas generator. Oxygen and hydrogen are tapped from the cycle for tank pressurizing using heat exchanger. The parallel set-up of the turbines requires a hot-gas vent to control the mixture ratio. Although the design is not totally complete yet, it is likely that the set-up with 2 turbine exhaust lines will be built as shown. The alternative (Figure 5 [20]) would be to use these lines for film cooling, as they are used in all other induction current engines (with the exception of HM7). It has been determined that this technology presents great difficulties in Europe. The amount of hydrogen needed to dump cool the nozzle would have to be decreased.

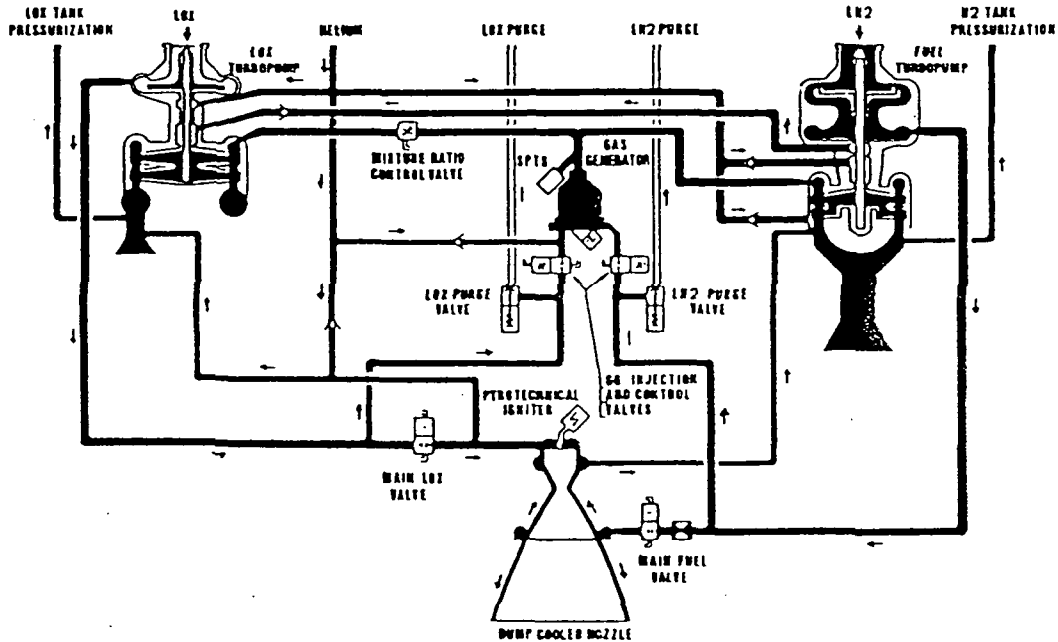


Figure 4: HM60 Combustion Chamber Cycle (Source: SEP)

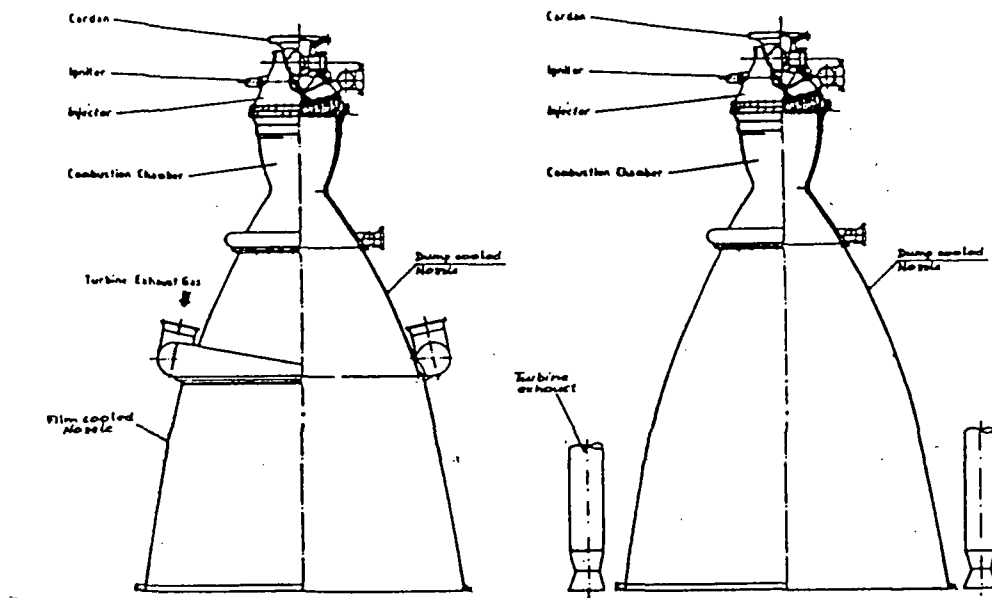


Figure 5: Alternative Use of HM60 Nozzles with Dump Cooling. Left: Additional Film Cooling using Turbine Exhausts. Right: Separate Exhaust Lines.

The history of the European cryogenic engine does not /12 begin with HM7 and HM60: Preparatory projects began already in 1960 at SEP (SEPR), and already in 1962 a contract existed to develop a 4-chamber drive system with 6 t thrust. This system satisfied all the technological data of the subsequent HM7 engine [12], [22], and, using an HM4 engine, led to the HM7 in 1973. MBB began investigating high-pressure engines in 1967 [21] and cryogenic engines in 1962. A main current H<sub>2</sub>/O<sub>2</sub> experimental engine (HPC, high-pressure chamber in Figure 3) had attained 210 bar chamber pressure as early as 1968. This engine was developed in conjunction with Rocketdyne and led to SSME taking over combustion chamber production technology. Unfortunately, the previously mentioned 15-year pause followed, during which time no research was done in Europe on chemical liquid drive. The one exception to this was SEP's development of the HM7. Unfortunately as well, this gap included the area of small, pressure-driven engines with storable fuels, which are necessary for advanced stored control systems and as kick stage engines. The Federal Republic became the world leader in this area in 1970 with MBB's 10N and 400N symphony engines. Today, similar engines having a far greater thrust range are available from numerous firms in the USA.

Overall, the situation today is such that Europe must catch up in the following areas of chemical liquid engines (a list, which could be expanded easily):

- Mechanical transfer: Cryogenic high-pressure turbopumps, entire field of technology, especially, however, cryogenically cooled bearings at high speeds. (HM60 is said to exhibit 45% more stress than HM7. A value of 75% over that of HM7 was planned in Japan for LE-7. HM60 lies below, LE-7 above the value of SSME.)
- Combustion chamber: High-pressure/high-temperature materials (for example, replacement for the Narloy Z



used in the SSME, since Cu Ag Zr alloys are neither available in sufficient amounts in Europe, nor has the processing of same been sufficiently developed, especially for pre-combustion chambers.) New constructions and cooling with LOX must be investigated.

- Nozzles with altitude compensation: Extendable, bundled, unconventional.
- Preparation methods for injection systems, cooling systems, nozzles. Cost reduction through automation and/or robot utilization.
- Theory: Thermodynamics and kinetics of high- /13 pressure fuel preparation and combustion, flow mechanics in all parts of the engine, modeling of combustion stability, design of mechanisms to prevent combustion instability.
- Engine development: Engines in the medium thrust range from 0.3 to 3.0 t.

#### 4. The Future European Launch Rocket ARIANE 5P

Research carried out up to 1983 in France by CNES and in the Federal Republic by an industrial group ("ZETK") came up with the concepts shown in Figure 6 [24], [25], which are characterized, above all, by three requirements:

- Increase of the European LEO payload capacity from the present 4 - 6 t (ARIANE 3/4) to at least 15 t;
- STS compatibility in the specific transport price to GEO with at least similar space (diameter) available for use, and

- Inclusion of manned LEO missions for Europe by means of a retrievable system with which payloads could also be returned.

The demand for manned flight proved to be the foremost element in determining a design: On the one hand, the winged HERMES retrievable craft, proposed by CNES, set the course for LEO minimum payload sizes and with it for the absolute size of the transport. On the other hand, this led to the demand of at least 98% dependability.

The further requirements that this transport be available for use in 1995 (manned beginning in 1997) and that takeoff costs be held under 50 MAU (114 MDM) for at least 5200 kg to GTO, led the CNES to select A5P (Figure 7). This choice has been subject to some criticism: For one, a small rocket would be able to handle all the planned missions up to the year 2000 (with the exception of the HERMES mission). Other critics take exception to the fact that the CNES has knowingly rejected the demand for continued development possibilities of the system.

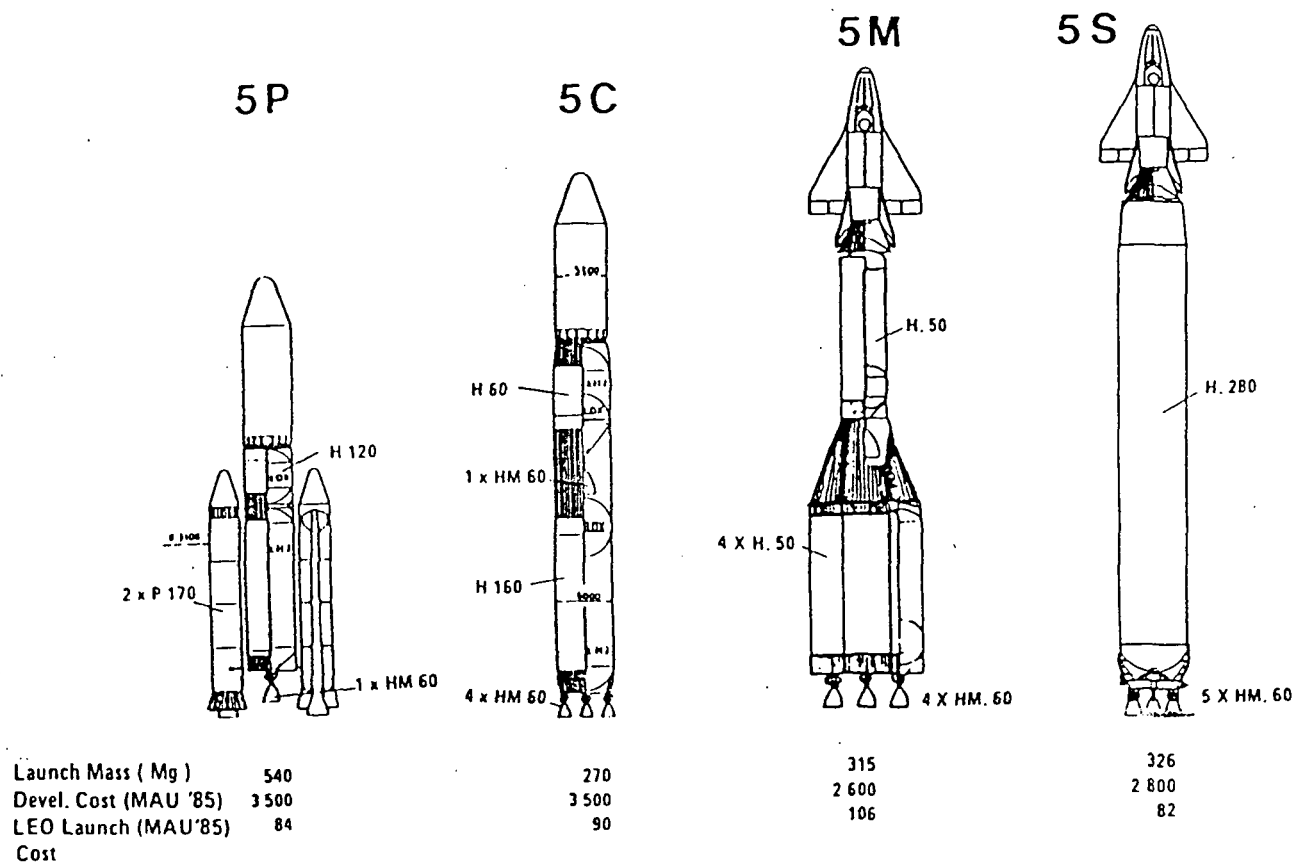


Figure 6: Different ARIANE 5 Concepts 5P: with solid boosters (P = "powdered"); 5C: pure cryogenic 2-stage (C = "cryogenic"); 5M: Modular constructed two stage (M = "Modular"); 5S: Single stage (S = "Single Stage") with detachable engines

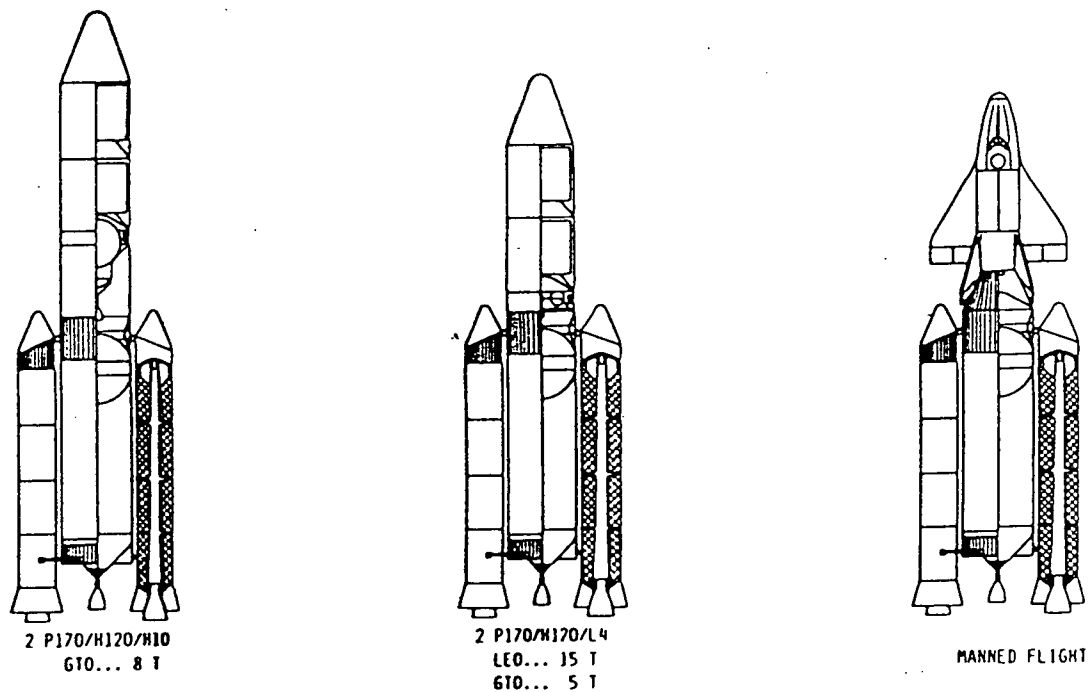


Figure 7: Three Versions of the ARIANE 5P

ARIANE 5P will consist of a 1 1/2-stage system which /15  
has an H120 core stage (120 t fuel H<sub>2</sub>/O<sub>2</sub>, 1 HM60 engine) and  
two P170 solid boosters (each with 170 t solid fuel). It will  
carry three different upper stages and payloads to LEO or near  
to LEO:

- One cryogenic H10 upper stage (Figure 8, [26]) with 8 t  
GTO payload, with which up to three satellites can be  
brought to GTO simultaneously using corresponding  
apogee engines. This stage is also suited for  
scientific missions having large engine demands.

- One L4 stage (Figure 8) with storable fuels. With different fueling, this stage transports up to 15 t to LEO, but can also convey smaller payloads (5 t) to GTO.
- The HERMES retrievable system.

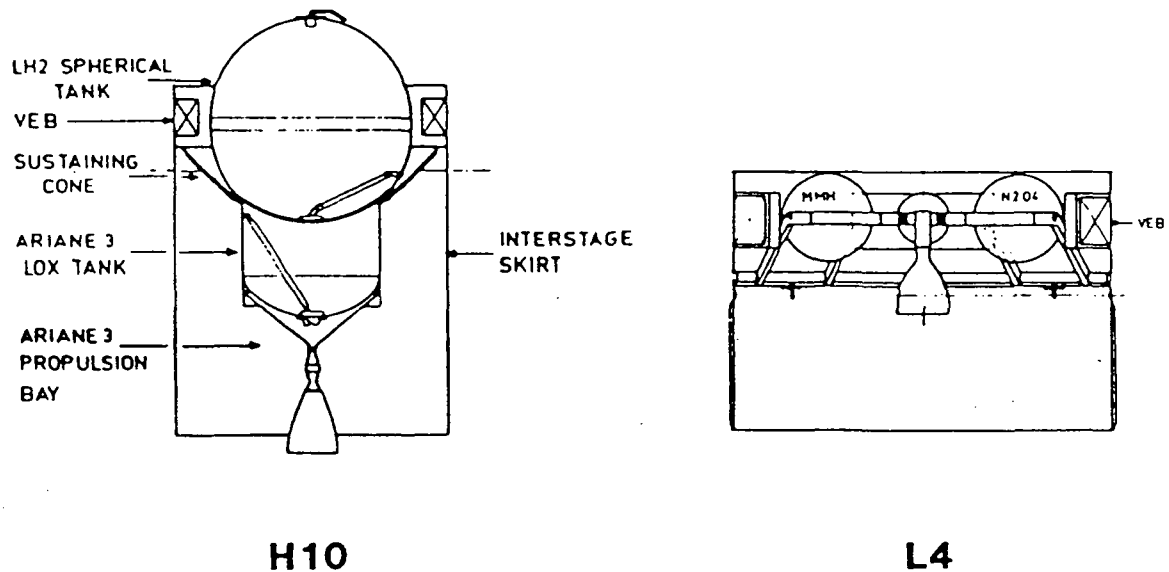


Figure 8: Both Upper Stage of the ARIANE 5P

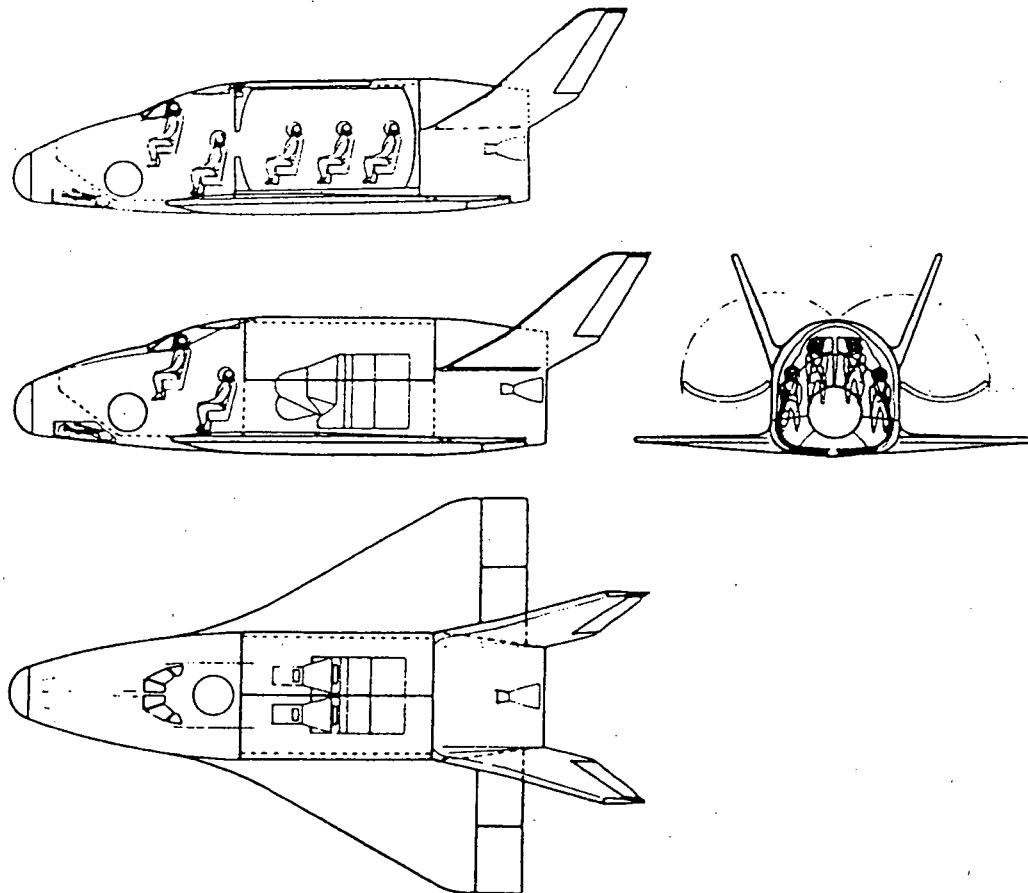
The new H10 upper stage for the A5P uses a new LH<sub>2</sub> tank together with LOX tank, propulsion bay, and HM7 engine of the H10 in the ARIANE 3/4 version. The range of uses for the H10 could be increased drastically, if it were to be converted into a type of "European Centaur" by means of re-start capability of the HM7 engine. This is not planned at present.

L4 uses a newly developed engine, whose dimensions /16 have not yet been defined. Thrust for 15 to 30 kN are under discussion. The decision will depend on the final layout of the HERMES, which will have the same engine (Figure 9) so that it will have a drive capacity of 400 m/s (LEO) to 600 m/s (solar-synchronous). This will make it possible for HERMES to carry 2500 kg fuel  $N_2O_4$  /MMH to attain an altitude of 400 to 800 km.

In addition, HERMES requires other small engines in the range from 10 to 100 N. These are necessary to complete its three functions [27]:

- Autonomous missions (with 2 pilots and 2 payload specialists) lasting from 1 to 4 weeks to carry out projects which correspond practically to the Spacelab pallet mode. The HERMES payload bay is only 3 m in diameter and 5 m long.
- In-orbit servicing, above all of platforms in /17 solar-synchronous orbits; crew as above; length of mission, 2 weeks.
- Access to space stations (from US or Europe) with 4 to 6 passengers and 4500 kg payload. Missions lasting 1 week or up to 90 days docked.

While H10 and L4 are clearly elements of the ARIANE 5, HERMES is primarily a French design. Alternative solutions to the problems involved in acquiring return technology are being investigated in the Federal Republic at present. Possibilities are either ballistic re-entry vehicles (as a complement to HERMES) or winged upper stages (as an alternative).



**Figure 9** HERMES Space Plane (Above left: Configuration for space station servicing; Below: Configuration with cargo for autonomous missions. Note: This set-up is in accordance with [24]; in the meantime, a design with only one tail flap has been suggested [28].)

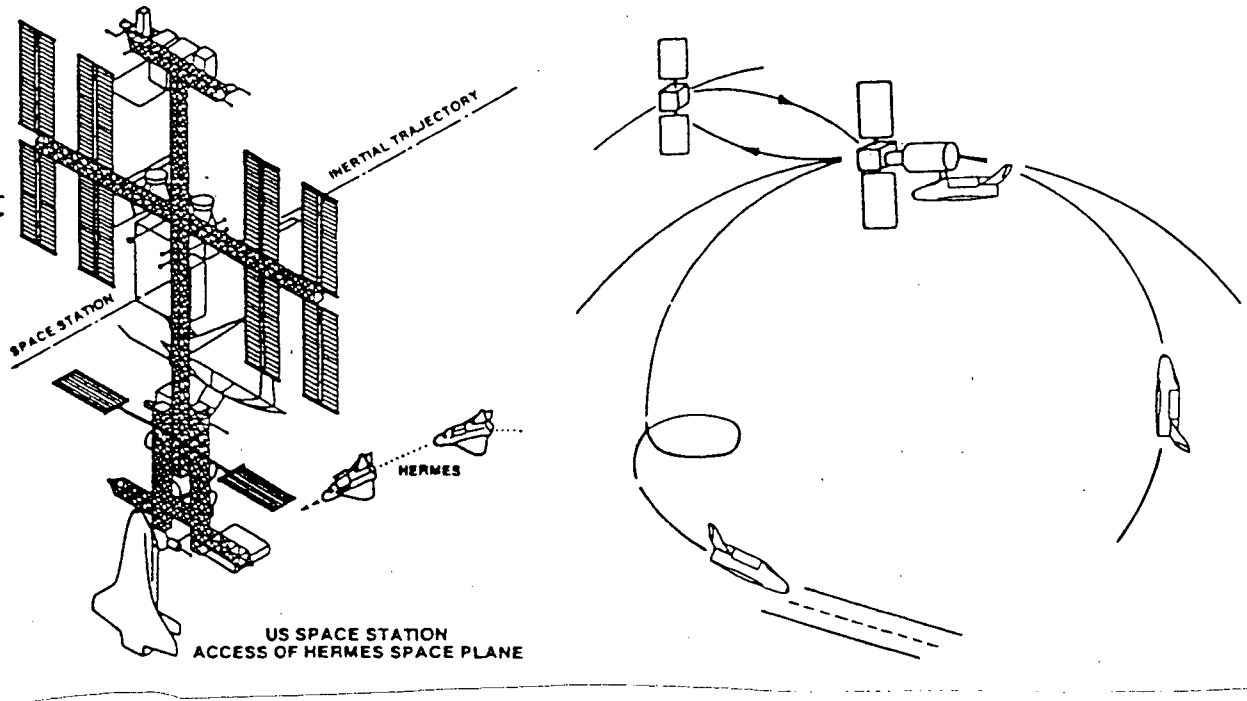


Figure 10 HERMES Approaching US Space Station (left), and Servicing an Element of the European Space Station (right).

It must also be mentioned in connection with the introduction of the ARIANE 5, that during its usage time, it will have to compete with and operate beside already known competitors, as well as not yet well-defined, but expected, new variations of the STS [29], [30].

Several examples are shown in Figure 11 [31], [32]. /18  
Because of environmental reasons, but also in order to increase



payload capacities, the USA is considering replacement of the STS's solid boosters with liquid fuels (storable or cryogenic).

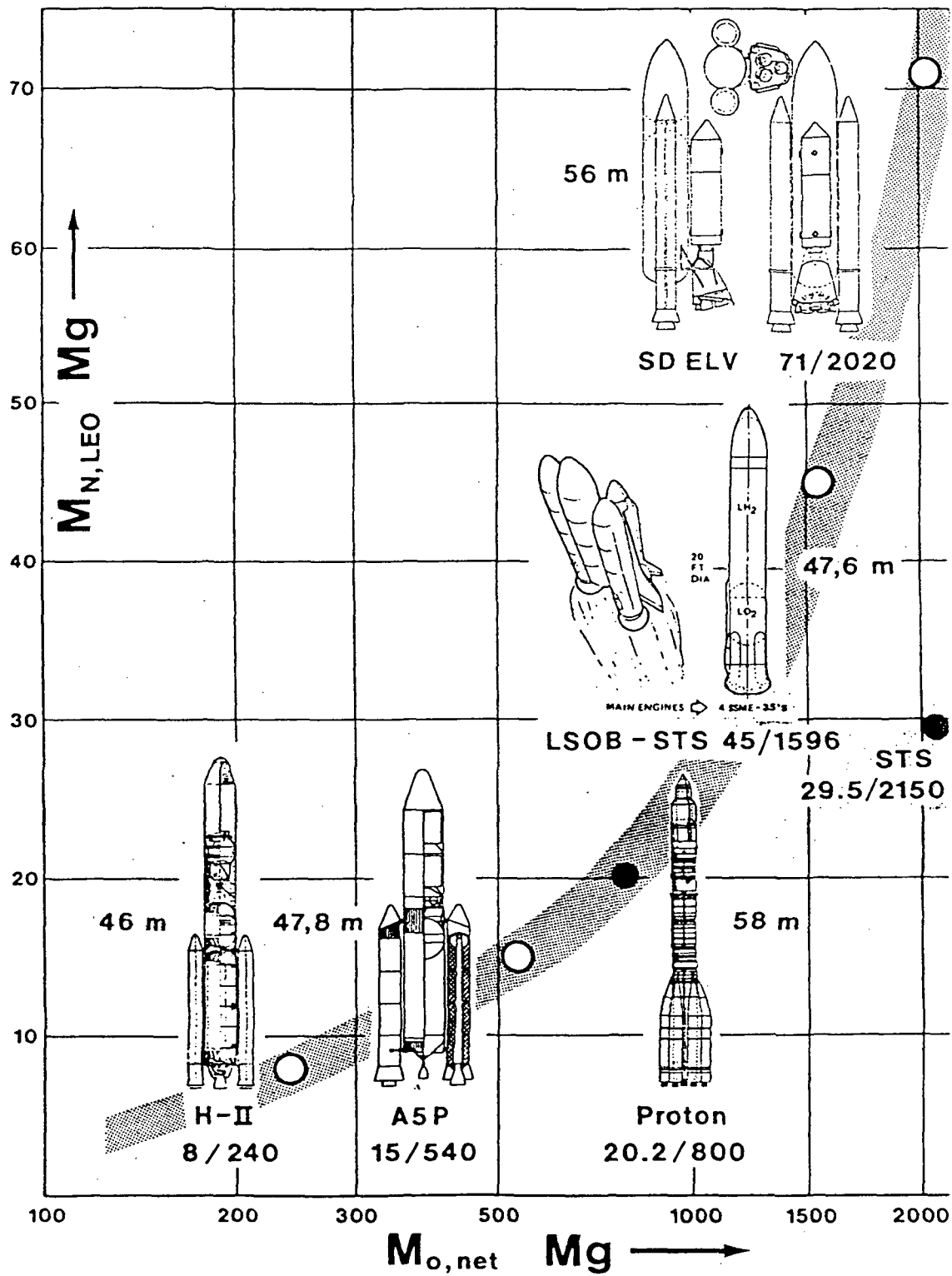
By substituting a payload capsule for the orbiter (which weighs 68 t), we obtain a loss device with 71 t payload. NASA considers this variation to be the most likely further development. As early as 1996 has been mentioned as a potential deployment date [30]. In addition to these competitors, the A5P will have to compete, as well, with the Soviet Proton and the Japanese H-11.

## 5. Orbital Drive and Transport Demands in LEO

An important discovery which the Americans made with the STS is that the orbiter proved to be too heavy and cumbersome for interorbital maneuvering in lower orbits. For this reason, an orbital maneuvering vehicle (OMV) is to be deployed as early as 1990 [30]. This vehicle will serve to pick up or deliver payloads in orbits at up to 2800 km. HERMES is to be able to orbit the sun at altitudes up to 800 km, a fact which leads to the question of whether Europe is not repeating the Americans' error.

The US space station will be the beginning point for transfer stages (OTVs) which return from GTO and GEO with the assistance of air friction. Their effect on the GEO transport market cannot be estimated yet.

Figure 11: Launch Rocket Scene 1995 - 2000  
(Figure follows on page 26)  
Shaded symbols: Presently in use. LSOB =  
Liquid strap-on booster; SDELV = Shuttle  
derived expendable launch vehicle.



An OMW would be necessary for Europe only as a measure for traffic between individual elements of a space station. Figure 12 shows a European concept [33]. As part of a modular system, such an OMW could also be used as a servicing vehicle. This is the case in the Columbus Space Station project currently under preparation in Europe.

In the IOC (initial Operating Capability); the Columbus Project consists of the following known elements [34]:

- A laboratory module attached to the NASA Space Station, but potentially also free-flying (which would then demand storage control, orbit correction and ranging facilities).
- Free-flying platforms in near orbits next to the laboratory module, but also on polar orbits. Primarily, unmanned service vehicles--as shown in Figure 13--will be used for these platforms.
- A resources module to assume the free-flying /20  
laboratory module's functions which the lab makes available when docked at the US space station.

In the subsequent AOC (autonomous operating capability) phase the system will have a pressurized module added to it, and large platforms with the resource module will be built. A manned service vehicle would be necessary then to take over the transport of astronauts (Figure 13) [34], [35].

The drive problems connected with the space station have not been fully investigated. Particularly the resource module has considerable maneuvering demands, and its limitation as service vehicle and/or OMV has not been defined yet.

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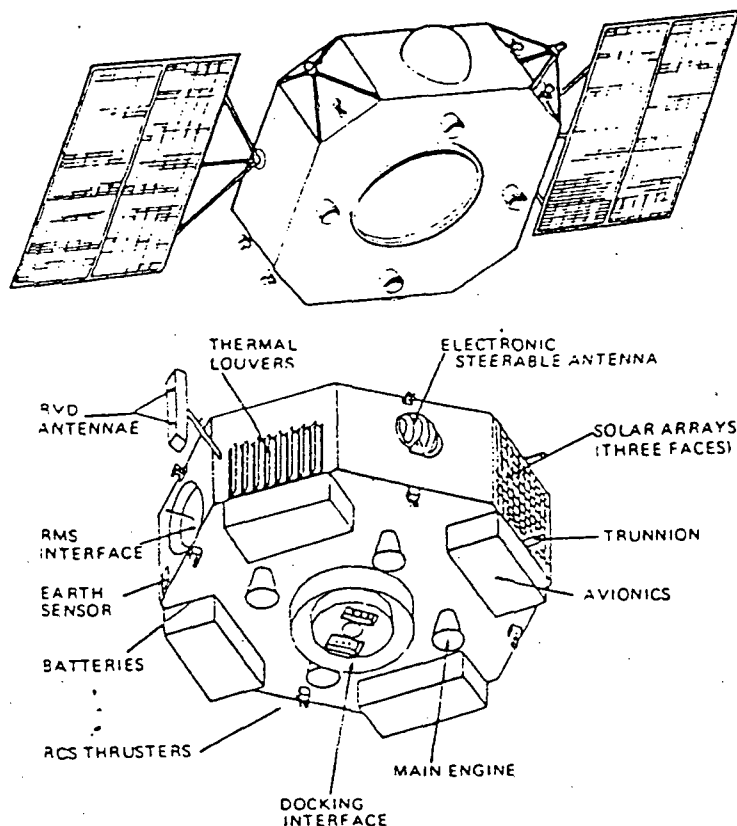


Figure 12: European Concept  
for Orbital Maneuvering  
Vehicles

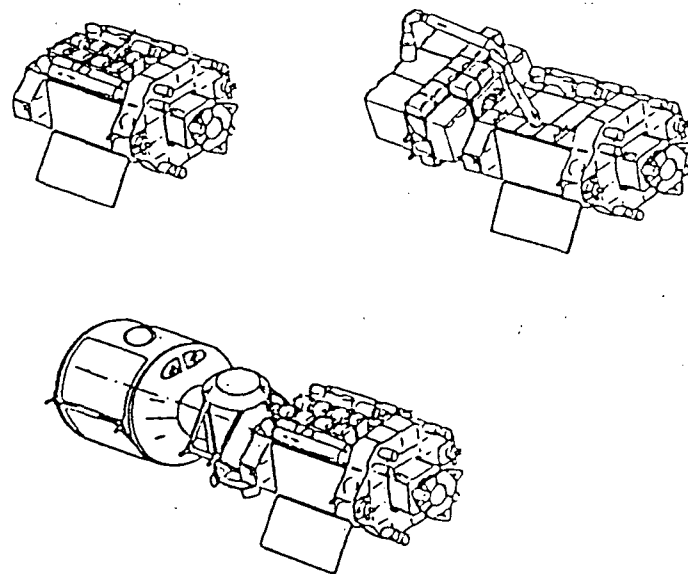


Figure 13: Unmanned (above:  
2 Versions, at right with  
Manipulator Arm) and Manned  
(below) European Service  
Vehicle.

Space stations, launch rockets, and retrievable systems /21 make up the marketable growth areas of space travel in the coming years. Construction and development of European space transport systems create demands on European technology, which must investigate and master this challenge if Europe is to compete successfully on the international scene in the future.

## REFERENCES

- 1 Anonymous, "ARIANE 3 -SPB 7.35 Strap-on-Booster," Spaceflight, Vol. 26, Dec. 1984, p. 459.
- 2 Ordahl, C. A. (McDonnell Douglas), "The MDAC Payload Assist Modules (PAM-A and PAM-D)," AIAA 9th Com. Sat. Conference, San Diego, March 1982, AIAA-82-0559.
- 3 Baker, M. J., et al., and E. L. Bangsund et al., (Boeing Aerospace), "IUS Status and Growth Potential," 33rd IAF Congress, Paris, Oct. 1982, IAF-82-353, IAF-82-05.
- 4 Aviation Week & Space Technology, "Defense Department to Retain Expendable Launchers as Backup to Shuttle,": March 18, 1985, p. 115.
- 5 Balzer, D. L. (RCA Astro Electronics), "Shuttle Compatible Orbit Transfer Subsystem (SCOTS)," 35th IAF Congress, Lausanne, Oct. 1984, IAF-84-14.
- 6 Spacetime Electronic & Paper Editions Daily, Vol. 2, No. 47, March 3, 1985, p. 220.
- 7 Rector III, W. F., and D. E. Charhut (General Dynamics Convair), "The Commercial Centaur Family," 34th IAF Congress, Budapest, Oct. 1983, IAF-83-233.
- 8 Mulready, R. C. (Pratt & Whitney Aircraft/UAC), "Pratt & Whitney Aircraft's Space Shuttle Main Engine," AIAA/SAE 7th Joint Propulsion Conference, Salt Lake City, Utah, June 1971, AIAA-71-658,
- 9 Wilson, L. D. (Aerojet Liquid Rocket Co.), "AJ-550 Space Shuttle Main Engine," AIAA/SAE 7th Joint Propulsion Conference, Salt Lake City, Utah, June 1971, AIAA-71-660.
- 10 Wagner, W. R. (Rocketdyne), "Future Higher Performance O<sub>2</sub>/H<sub>2</sub>-Engine Combustion Cycle Alternatives," AIAA/SAE 12th Propulsion Conf., Palo Alto, July 1976, AIAA-76-709.
- 11 Kirner, K. (MBB), "HM60 Thrust Chamber," Final Report on BMFT Study on HM60 Thrust Chambers, 1984.
- 12 Dardare, M. (SEPR), "Rocket Engines using Liquid Oxygen and Hydrogen," Translation from the French, SEPR Corporate Report, 1963.
- 13 Pouliquen, M. (SEP), "Development Progress of HM-7 LOX/LH<sub>2</sub> Rocket Engine for the Ariane 3rd Stage Propulsion System," 28th IAF Congress, Prag, Oct. 1977, IAF-77-91.

- 14 Souchier, A. (SEP), "Ariane 3 Third Stage Propulsion Systems and HM-7B Development," 34th IAF Congress, Budapest, Oct. 1983, IAF-83-387.
- 15 Katusuta, H., et al. (NASDA/NAL), "LE-5 Cryogenic Rocket Engine Development," 34th IAF Congress, Budapest, Oct. 1983, IAF-83-385.
- 16 Dederra, H. (MBB), "The European Ariane HM-7 Engine Compared to American Cryogenic Engines," DGLR-Committee Meeting on "Engines," Ottobrunn, April 1978.
- 17 Klett, F. P. (Rocketdyne), "Development of the Space Shuttle Main Engine," 34th IAF Congress, Budapest, Oct. 1983, IAF-83-386.
- 18 Diem, H. (Rocketdyne), "Advanced Space Engine for the Orbital Transfer Vehicle," 28th IAF Congress, Prag, Oct. 1977, IAF-77-101.
- 19 Yamawaki, K (NASDA), "Preliminary Study for H-II Rocket Plan," 35th IAF Congress, Lausanne, Oct. 1984, IAF-84-01.
- 20 Schmidt, G., et al. (MBB), "HM60 Thrust Chamber Performance Analysis," Jan. 1985, HM60-TR-0.90-007.
- 21 Drebs, H. (MBB), "Development of Liquid Rocket Engines at Messerschmitt-Boelkow-Blohm GmbH," AIAA-Paaper 72-1104, 1972.
- 22 Stoekl, K. (MBB), "On the Development History of the High-Pressure Main Current Rocket Engine in Germany," ZFW, 9/1, p. 1, Jan. 1985.
- 23 Mandeler, P. E. (SEP), "High Speed Bearings in Cryogenic Environment," 36th IAF Congress, Stockholm, Oct. 1985, IAF-85-194.
- 24 Anonymous (CNES), "Ariane 5/Hermes General Presentation," Paris, December 11, 1984.
- 25 Kleinau, W. (MBB), "Future European Launcher Concept (ARIANE 5)," ZETR-Planning Report, UR-V-156 (85), June 1985.
- 26 Marx, P., and H. Laporte-Weywada (CNES), "ARIANE 5, a New Launcher for Europe," 35th IAF Congress, Lausanne, Oct. 1984, IAF-84-03.
- 27 Anonymous (CNES), "HERMES: A Must for Europe," Presentation of the ESA-Ministry Conference in Rome, Jan. 1985.
- 28 Raillon, E. (CNES) "Ariane 5-Hermes, a New Space Transportation System for Europe," ONLINE Conference on Space Technology & Opportunity, Geneva, May 1985.

- 29 Jones, A. L. (Rockwell Int.), "Extension of Space Shuttle Capability," AAS 1979 Annual Meeting, Los Angeles, AAS-79-292, Oct. 1979.
- 30 Bekey, I. (NASA), "Emerging Capabilities in Space Transportation)," ONLINE Conference on Space Technology & Opportunity, Geneva, May 1985.
- 31 Anonymous, "Salyut: Soviet Steps Toward Permanent Human Presence in Space," US-Congress Technical Memorandum, Washington D. C., OTA-TM-STI-14, Dec. 1983.
- 32 Bond, A., and J. Parfitt, "The Proton Launcher," Spaceflight, Vol. 27, p. 318, July 1985.
- 33 Collet, J., and G. Peters (ESA), "ESA Space Station Activities," 34th IAF Congress, Budapest, Oct. 1983, IAF-83-30.
- 34 Altmann, G. (ESA), "Status of ESA's Planning for the Space Station," ONLINE Conference on Space Technology & Opportunity, Geneva, May 1985.
- 35 Ley, W. (DFVLR), "Columbus Status and Planning," RZT-Progress Report, Oberpfaffenhofen, Dec. 13, 1984.